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SOIL MICROORGANISM POPULATION DYNAMICS IN WEAK ELF ELECTROMAGNE--ETC(U)

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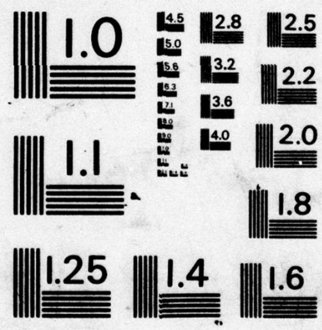

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SOIL MICROORGANISM POPULATION DYNAMICS

IN WEAK ELF ELECTROMAGNETIC FIELDS

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G. M. Rosenthal, Jr.
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Chicago, Illinois 60637

FINAL REPORT, NOVEMBER 1976

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Soil samples were exposed in the laboratory to an electric field of 1 volt per meter rms and a magnetic field of 1 gauss rms at a frequency of 60 Hz for up to 16 weeks. Soil samples were assayed for total number of aerobes, anaerobes, and fungi and for microorganisms having specific biochemical functions. Results indicated no significant effects of the ELF fields on the concentration of microorganisms in the soil.

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FOREWORD

This study was performed under subcontract to IIT Research Institute for the U. S. Naval Electronic Systems Command under Contract No. 00039-71-c-0111, IITRI - E6185. The work here described follows from strategies and methods that I suggested in broad outlines and general terms. Details associated with the treatment of soil in the laboratory and with the isolation, culture and counting of microbial populations were handled by Sol Miller, research microbiologist in the Biology Division of IITRI. Statistical analysis of Mr. Miller's data was completed by IITRI personnel, as were several drafts of the report that follows.

I concur in the conclusions as stated.

Respectfully submitted,

G. M. Rosenthal, Jr.
Biological Sciences Collegiate Division
The University of Chicago

SUMMARY

Soil samples from a pine plantation and a meadow were exposed in the laboratory to an electric field of 1 volt per meter rms and a magnetic field of 1 gauss rms at a frequency of 60 Hz for up to 16 weeks. Soil samples were assayed at 0, 2, 4, 8, and 16 weeks for total number of aerobes, anaerobes, and fungi and for microorganisms having specific biochemical functions, i.e., nitrification, denitrification, urea decomposition, cellulose decomposition and sulfate reduction. Results indicated no significant effects of the ELF fields on the concentration of microorganisms in the soil.

TABLE OF CONTENTS

		Page
1.	INTRODUCTION	1
2.	EXPERIMENTAL DESIGN AND METHODS	1
	2.1 Culture Methods and Conditions	1
	2.2 Electromagnetic Field	3
3.	RESULTS AND DISCUSSION	3
4.	CONCLUSIONS	10
5.	REFERENCES	12
	APPENDIX A	

LIST OF TABLES

Table		Page
1	GROWTH MEDIA USED FOR ASSAY OF SOIL MICROORGANISMS	4
2	GROUPS OF MICROORGANISMS USED IN THE STATISTICAL ANALYSIS	5
3	MEAN GRAND TOTAL - VARIABLE 11	6
4	MEAN NITROGEN CYCLE TOTAL - VARIABLE 12	6
5.	TREATMENT VERSUS TIME INTERACTIONS FOR VARIABLES 11 AND 12	7
6	MEAN AND CONFIDENCE LIMITS FOR TOTALS	8
7.	ANALYSIS OF VARIANCE, VARIABLE 11 - GRAND TOTALS	9
8	ANALYSIS OF VARIANCE, VARIABLE 12 - NITROGEN CYCLE TOTALS	10
9	MEAN CONCENTRATION OF VARIOUS GROUPS OF MICROORGANISMS	11

1. INTRODUCTION

This study was performed in 1971 as part of a program to determine possible biologic effects of ELF electromagnetic environments similar to those envisaged in the vicinity of the Navy's proposed ELF Communication System, e.g., Projects Sanguine and Seafarer.

Samples of undisturbed soil were exposed to ELF electric and magnetic fields under controlled laboratory conditions. The microbial population of soil samples exposed to the ELF fields was periodically compared with that of soil samples not exposed to the ELF fields which served as the control for this study. The microbial population was evaluated by assays of total numbers of aerobic and anaerobic microorganisms and of groups of microorganisms which are known to have specific biochemical functions related to soil fertility, e.g., nitrogen fixing and nitrifying or denitrifying bacteria.

2. EXPERIMENTAL DESIGN AND METHODS

Thirteen soil samples from a pine plantation and thirteen soil samples from a meadow were obtained for this study. Each sample was a one foot cube and was disturbed as little as possible. Four samples of each soil type were exposed to an electric field; four samples of each type were exposed to a magnetic field; four samples of each type served as controls, i.e., not exposed to either an electric or magnetic field; and one soil sample of each type was assayed at the beginning of the study to provide zero time baseline values. The study was conducted in an environment controlled with respect to light, soil moisture, and temperature.

2.1 Culture Methods and Conditions

Each soil sample was placed in a plastic container 12 in. x 12 in. x 14 in. high with an open top. The soil made contact with two stainless steel plates attached to two opposite inside walls of the container. Voltage applied to these

plates established the electric field in the soil sample. Voltage applied to coils surrounding the container provided the magnetic field. Lighting was supplied above the soil samples from power groove fluorescent bulbs supplemented with incandescent bulbs to provide a spectrum simulating sunlight and an average intensity of 600-foot candles at the soil surface over all the containers. The lighting was controlled by a time clock to provide a diurnal cycle of ten hours of light and 14 hours of darkness. The temperature in the air-conditioned room was maintained at $70 \pm 1^{o}F$ during the night but due to the heat generated by the lights the temperature increased to $76 \pm 1^{o}F$ during the day.

Each plastic container had a 1/2 inch drain hole fitted with connectors and plastic tubing to facilitate mositure control. Approximately two liters of water were added to each plastic container three times per week to maintain approximately 50 percent saturation of the soil. To simulate a saturating rainfall, the plastic tubing was clamped off for 30 minutes while the containers were filled with water. The saturation of the soil was done one day prior to each sampling period.

The treatments were applied for a total of 16 weeks. Small sampling blocks of soil were removed from each set of containers at 0, 2, 4, 8, and 16 weeks.

Two blocks of soil four inches wide by four inches deep by two inches thick were removed from the center of each container at each sampling time. The blocks were obtained with specially designed tools to avoid compacting the soil. For microbiological assays the top one inch of the soil block was removed and the rectangular block split with a sharp instrument to a size approximately 3/4 inch x 1-1/2 inch x 3 inches, weighing 100 grams. The samples for microbial analyses were weighed on sterile aluminum foil and antiseptic techniques were rigorously adhered to throughout the assay procedure. Each 100 gram sample was transferred to a three or four liter flask containing 900 milliliters of sterile distilled water and agitated on a shaker for 20 to 30 minutes. The resulting slurries were allowed to

settle for two to three minutes and ten milliliters of the supernatant were transferred to 90 ml of sterile distilled water. Further dilutions were made by transfers of one milliliter aliquots to nine milliliter water blanks to give 10^{-4} or 10^{-5} dilutions on each of 11 different media for the 13 groups of microorganisms shown in Table 1. For spore assays, appropriate dilutions of each sample were heated at 80°C for ten minutes prior to plating. The methods of assay and the formulae and preparation of media used were those described by Waksman[1], Fred and Waksman[2] and Black.[3] After incubation the colonies on the plates were counted and the results were calculated in terms of colony forming units per gram (CFU/g) of dry soil.

As appropriate, biochemical tests were performed to verify the presence of nitrifying, denitrifying, urea decomposing, cellulose decomposing and sulfate reducing groups of bacteria.

2.2 Electromagnetic Field

The apparatus used to generate the ELF electromagnetic fields was designed to simulate the environment in the vicinity of an ELF Communications antenna system. A detailed explanation of the theory of this type of apparatus has been previously given.[4] For these experiments, the apparatus was installed and regularly monitored by engineers from the Electronics Division of the IIT Research Institute. In all experiments, the magnetic component of the experimental environment was 1 gauss rms at 60 Hz and the electric field was 1 volt/meter rms at 60 Hz. (See Appendix A)

3. RESULTS AND DISCUSSION

The two types of soil, meadow and pine plantation, were assayed for total number of aerobes, anaerobes and fungi and for microorganisms having specific biochemical functions, i.e., nitrification, denitrification, urea decomposition, cellulose decomposition and sulfate reduction. The frequency of isolation of urea and cellulose decomposing and sulfate reducing bacteria in any of the samples was so low that data from these groups were not amenable to statistical analysis. Assays for 10 groups

Table 1

GROWTH MEDIA USED FOR ASSAY OF SOIL MICROORGANISMS

Type of Microorganisms	Medium
Total aerobes Total aerobic spores	Sodium albuminate agar
Total anaerobes Total anaerobic spores	Nutrient agar + glucose
Total fungi	Glucose, peptone agar, pH 3.6-3.8
Nitrogen fixing aerobes	Nitrogen free manitol agar
Nitrogen fixing anaerobic spores	Glucose phosphate, nitrogen free agar
Nitrifying $NH_3 \rightarrow NO_2$	Ammonium sulfate agar
Nitrifying $NO_2 \rightarrow NO_3$	Sodium nitrate agar
Denitrifying $NO_3 \rightarrow NO_2 \rightarrow NH_3$	Asparagin, nitrate, citrate agar
Urea decomposing	Urea, citrate agar
Sulfate reducing	Asparagin, sodium lactate solution
Cellulose decomposing	Ammonium sulfate, cellulose solution

of microorganisns shown in Table 2 provided observations satisfactory for analysis of variance. For analysis the 10 groups were designated as ten variables and two additional variables were formed by combining selected groups of microorganisms. Total aerobes, anaerobes and fungi were combined to obtain a Grand Total, variable 11. The organisms involved in the nitrogen cycle were grouped to obtain a Nitrogen Cycle Total, variable 12. These two totals tend to summarize the data and are used to illustrate the analysis applied to all variables.

The colony counts obtained for each soil sample were transformed to logarithms, and the logarithms were used for the analysis of variance and the multiple range test. The significance of the differences between various treatments is reported

Table 2

GROUPS OF MICROORGANISMS USED IN THE STATISTICAL ANALYSIS

Variable	Type of Microorganisms
1	Total aerobes
2	Total aerobic spores
3	Nitrifying, $NH_3 \rightarrow NO_2$
4	Nitrifying, $NO_2 \rightarrow NO_3$
5	Denitrifying, $NO_3 \rightarrow NO_2 \rightarrow NH_3$
6	Total fungi
7	Nitrogen fixing aerobes
8	Total anaerobes
9	Total anaerobic spores
10	Nitrogen fixing anaerobic spores
11 (Grand Total)	Variables 1 + 6 + 8
12 (Nitrogen Cycle Total)	Variables 3 + 4 + 5 + 7 + 10

at $\leq$ 5% probability level. The geometric means calculated from the observed values for Grand Total and Nitrogen Cycle Total are shown in Tables 3, 4, and 5.

Analysis of the data shown in Table 3 indicates that the differences in CFU/g for the Grand Total group of microorganisms within each type of soil were not significant as shown in Table 6. Thus the effect of the treatment appeared to be absent. On the other hand the difference in mean counts between the two soil samples was significant. Grand Total means in pine plantation and meadow soils were 151×10^5 and 272×10^5 CFU/g, respectively as shown in Table 6. A similar observation is made in reviewing the counts of the Nitrogen Cycle Total in Table 4.

Table 3

MEAN GRAND TOTAL - VARIABLE 11
(Soil x Treatment)

	CFU x 10^5/g of Soil		
	Pine	Meadow	Mean
Control	171	189	180
Magnetic	168	264	211
Electrical	120	405	220
Mean	151	272	203

Table 4

MEAN NITROGEN CYCLE TOTAL - VARIABLE 12
(Soil x Treatment)

	CFU x 10^5/g of Soil		
	Pine	Meadow	Mean
Control	259	507	362
Magnetic	239	698	408
Electrical	179	697	352
Mean	223	627	374

The differences in counts within the soils were not significant while the differences in means between the two soils were significant. The mean concentrations of Nitrogen Cycle Total microorganisms in the pine plantation and meadow soils were 223 x 10^5 and 627 x 10^5 CFU/g, respectively.

Similarly, the data shown in Table 5 indicate that the interactions between treatment and the sampling times of 2, 4, 8 and 16 weeks were not significantly different for the two groups of microorganisms.

Table 5

TREATMENT VERSUS TIME INTERACTIONS FOR VARIABLES 11 AND 12

	Sampling Time, Weeks			
	2	4	8	16
	CFU x 10^5/g Soil			
Grand Total (V-11)	273	210	176	168
Nitrogen Cycle Total (V-12)	533	326	317	354

The geometric means and 95% confidence limits for Grand Total and Nitrogen Cycle Total are shown in Table 6. The pine plantation and meadow soils were significantly different for both the Grand Total and the Nitrogen Cycle Total variables. The time variable was not significant. A linear trend seems apparent for the Grand Total. The mean Nitrogen Cycle Total also starts at a high concentration and is lower in latter samples. These trends were not proved to be statistically significant. The effect of time could vary between soils or as a function of treatment, but these interactions also were shown to be non-significant by the analysis of variance.

Table 7 shows the analysis of variance for variable 11 - Grand Total. The total sum of squared deviation from mean is divided into several component parts. The main effects, namely soil (S), time (T), and treatment (R) as well as their interaction S x T and R x S are included. The linear trend with respect to time interaction with treatment is indicated as R x T (l). Higher order R x T components and the third order R x S x T are pooled to estimate the effect of sample-to-sample variation. The two separate cores of soil examined provided a measure of variation within samples. Because of loss of some samples due to technical difficulties instead of the expected 47 degrees of freedom, 45 were available. Similarly instead of 24 degrees of freedom for core to core variation only 22 were available to determine the effect within sample error.

Table 6

MEAN AND CONFIDENCE LIMITS FOR TOTALS

Concentration, CFU x 10^5/g Soil

	Grand Total		Nitrogen Cycle Total	
	Mean	95% C.L.*	Mean	95% C.L.*
SOIL				
Pine	151	(112-204)	223	(165-302)
Meadow	272	(201-368)	637	(470-863)
TIME				
2 weeks	273	(178-419)	533	(347-820)
4 weeks	210	(137-322)	326	(212-502)
8 weeks	176	(115-270)	317	(206-487)
16 weeks	168	(110-258)	354	(230-545)
TREATMENT				
Control	180	(124-261)	362	(250-525)
Magnetic	211	(146-305)	408	(281-592)
Electric	220	(152-318)	352	(243-511)
SOIL X TREATMENT				
Pine, Control	171	(101-289)	259	(153-439)
Pine, Magnetic	168	(99-284)	239	(141-404)
Pine, Electric	120	(71-203)	179	(106-303)
Meadow, Control	189	(112-319)	507	(300-858)
Meadow, Magnetic	264	(156-446)	698	(412-1,182)
Meadow, Electric	405	(240-684)	697	(412-1,180)

*95% C.L. are the confidence limits upon the estimate of the mean of the .95 level.

Table 7

ANALYSIS OF VARIANCE, VARIABLE 11 - GRAND TOTALS

Effect	d.f.	Sum of Squares	Mean Square	F	P
Soil, S	1	0.78796	0.78796	15.86	<0.005
Time, T	3	0.32901	0.10967	2.21	n.s.
S x T	3	0.12239	0.04080	0.82	n.s.
Treatment, R	2	0.06921	0.03460	0.70	n.s.
R x S	2	0.49212	0.24606	4.96	<0.05
R x T(1)	2	0.03408	0.01704	0.34	n.s.
Between Sample Error	10	0.49684	0.04968	3.47	<0.01
Within Sample Error	22	0.31462	0.01430		
Total	45	2.64623			

As seen in Table 7 the initial test of Between Sample Error compared with Within Sample Error indicated that the former error is larger by a ratio of 3.47. Thus, all other tests of significance were made with respect to this sample to sample variance. The F-ratio for Soil (S) and the interaction between treatments and soil (R x S) were significant. This difference between soils was obvious in Table 3. To include the interaction R x S in a model for soil and treatment effects the treatment (R) effect terms must be included. Thus since R is not significant alone the combination R and R x S must be tested to determine the significance of the R x S interaction. This combination (with 4 degrees of freedom) was not significant, indicating that the extreme for the electrical treatment seen in Table 3 can be attributed to sampling variation.

Table 8 shows the analysis of variance for variable 12 - Nitrogen Cycle Total. Again the sample variation was greater than the measurement errors. The differences

Table 8

ANALYSIS OF VARIANCE, VARIABLE 12 - NITROGEN CYCLE TOTALS

Effect	d.f.	Sums of Squares	Mean Square	F	P
Soil, S	1	2.42499	2.42499	50.08	<0.005
Time, T	3	0.39814	0.13271	2.74	<0.10
S x T	3	0.21781	0.07260	1.50	n.s.
Treatment, R	2	0.03706	0.01852	0.38	n.s.
R x S	2	0.18098	0.09049	1.87	n.s.
R x T(1)	2	0.06866	0.03433	0.71	n.s.
Between Sample Error	10	0.48422	0.04842	4.44	<0.005
Within Sample Error	22	0.23994	0.01091		
Total	45	4.05180			

between soils were significant while sampling time showed a borderline effect which was not significant at the 5% probability level. The effects of the other variables were clearly not significant.

Table 9 shows the geometric mean counts of all groups of microorganisms isolated from the soils. The data indicate that the variations in the means are primarily related to soil sample.

The effect of treatment is shown to be non-significant for both variables. Analysis of variance did show a marginal (≤.05) level of significance for the soil x treatment interaction for the Grand Total. Therefore, the mean for each combination of soil and treatment is shown for both variables.

4. CONCLUSIONS

Results of this study did not indicate any significant effects of magnetic or electric energy, at the levels tested, on the concentration of microorganisms in soil. The differences observed could be ascribed to the type of soil and sampling variations.

Table 9

MEAN CONCENTRATION OF VARIOUS GROUPS OF MICROORGANISMS

	Concentration, CFU x 10^5/g Soil									
	Total Aerobes	Total Aerobic Spores	Nitrifying $NH_3 \rightarrow NO_2$	Nitrifying $NO_2 \rightarrow NO_3$	Denitrifying $NO_3 \rightarrow NO_2 \rightarrow NH_3$	Total Fungi	N_2 Fixing Aerobes	Total Anaerobes	Total Anaerobic Spores	N_2 Fixing Anaerobic Spores
SOIL										
Pine	128.5	9.36	121.4	7.26	17.55	.556	64.3	17.99	6.52	2.94
Meadow	245.5	14.50	282.0	34.12	35.81	.440	237.1	14.22	6.43	2.71
TIME										
2 weeks	245.5	7.73	217.0	22.22	44.67	.227	206.5	19.14	7.41	1.99
4 weeks	181.1	8.88	173.3	9.53	23.93	.489	103.3	18.88	9.57	3.85
8 weeks	142.6	12.43	186.1	14.51	27.04	.678	75.9	27.80	9.53	3.09
16 weeks	158.1	24.58	167.3	20.00	13.65	.789	142.6	6.49	2.59	2.68
TREATMENT										
Control	151.0	11.81	174.8	15.42	24.72	.449	129.0	16.90	6.04	2.47
Magnetic	189.2	13.06	218.9	12.30	28.31	.510	123.8	14.83	6.92	3.79
Electric	197.2	11.31	165.3	20.61	22.54	.528	111.6	16.26	6.49	2.41
SOIL x TREATMENT										
Pine, Control	139.0	10.01	130.3	8.95	18.71	.615	89.3	25.64	6.01	2.92
Pine, Magnetic	146.6	11.89	139.1	4.42	22.39	.510	63.1	18.41	8.53	4.02
Pine, Electric	104.5	7.94	98.6	9.70	12.38	.548	46.9	12.30	5.40	2.17
Meadow, Control	164.1	13.95	234.6	26.55	32.58	.327	193.0	11.14	6.04	2.08
Meadow, Magnetic	244.3	14.35	344.1	34.36	35.73	.512	263.6	11.94	5.62	3.58
Meadow, Electric	372.4	15.25	277.0	43.75	39.45	.508	266.1	21.53	7.80	2.68

5. REFERENCES

1. Waksman, S.A., Principles of Soil Microbiology, Williams and Wilkins Co., Baltimore, (1932).

2. Fred and S.A. Waksman, Laboratory Manual of General Microbiology, McGraw-Hill Book Inc., New York, New York, (1928).

3. Black, C.A., et. al., Eds, Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, American Society of Agronomy Inc., Madison Wisconsin, (1965). Chapts. 98-107.

4. ELF Earth Return Circuit Electromagnetic Fields and Their Simulation, IIT Research Institute, E6185-4, October 1971.

APPENDIX A

ELECTRIC AND MAGNETIC FIELD SIMULATORS

1. INTRODUCTION

Specific apparatus to provide the ELF electromagnetic fields used during the soil microorganism study effort, were designed and constructed by IIT Research Institute. The apparatus is described in the following paragraphs.

2. E-FIELD SIMULATOR

2.1 *Introduction*

One of the E-field simulators required for the laboratory studies of E-field effects on soil organisms is shown in the attached photographs (Figures A-1, A-2). The following is a description of the E-field simulator design and the results of the preliminary performance tests.

2.2 E-Field Simulator Design

The basic design requirement of the E-field simulator is that it must produce a uniform, 1 volt/meter 60 Hz electric field within the selected soil samples. The soil samples are one-foot cubes; therefore, the desired E-field can be obtained by applying 0.304 volt between two parallel one square foot electrodes which make uniform contact with opposite sides of the soil sample. Hence, the soil containers have been modified with suitable stainless steel electrodes and three low voltage sources have been constructed.

A schematic of the sources is shown in Figure A-3. As shown, each source is capable of exciting 1 to 4 soil samples. The low output impedance results in a source voltage that is essentially independent of the load impedance for load impedances greater than 30 ohms. Thus, the soil samples can be watered or removed without affecting the source voltage and resulting E-field. Further, the output voltage can be adjusted by means of the potentiometer and is available at a coaxial output for measuring convenience.

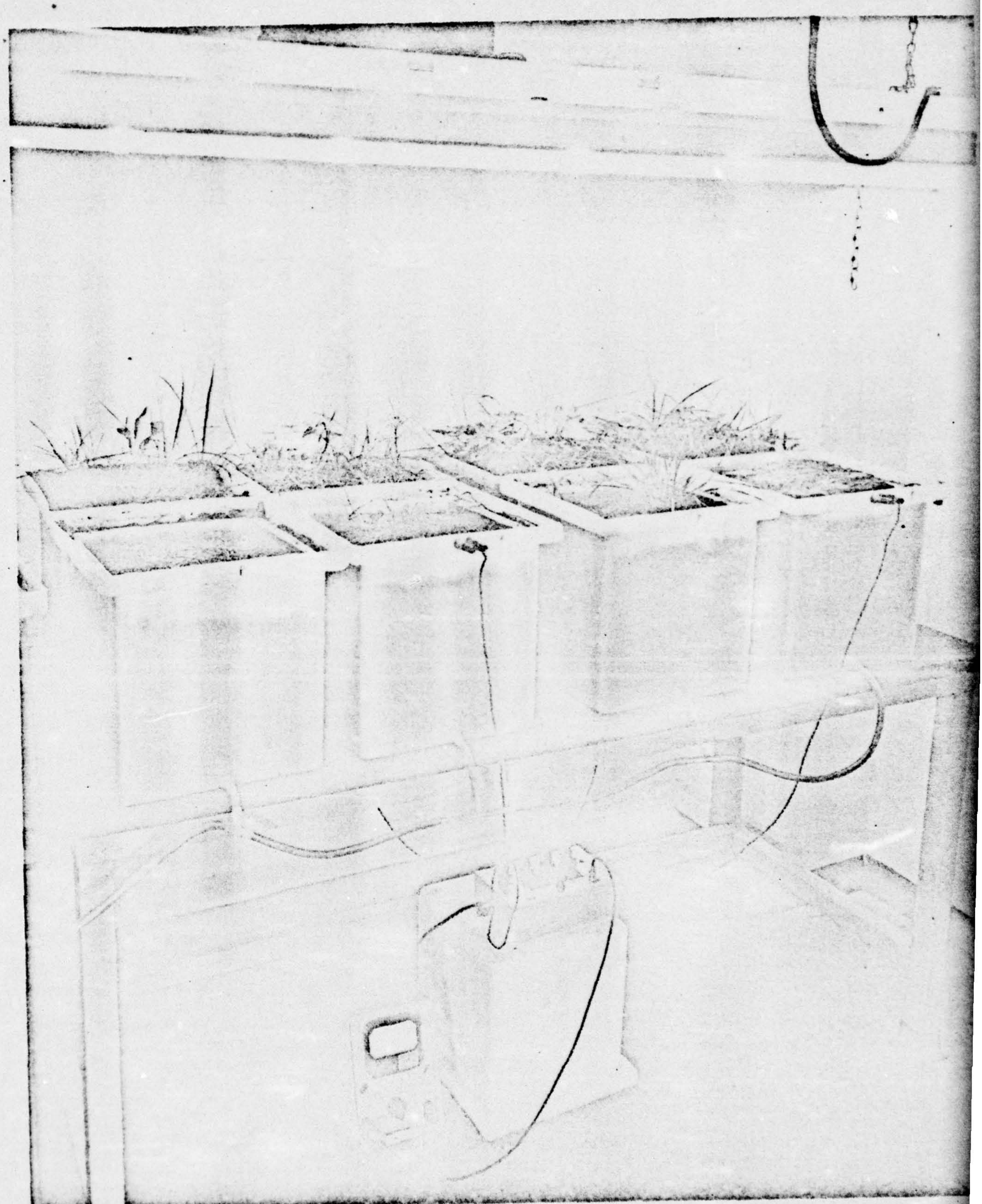

Figure A-1 Soil Samples in E-field Simulator

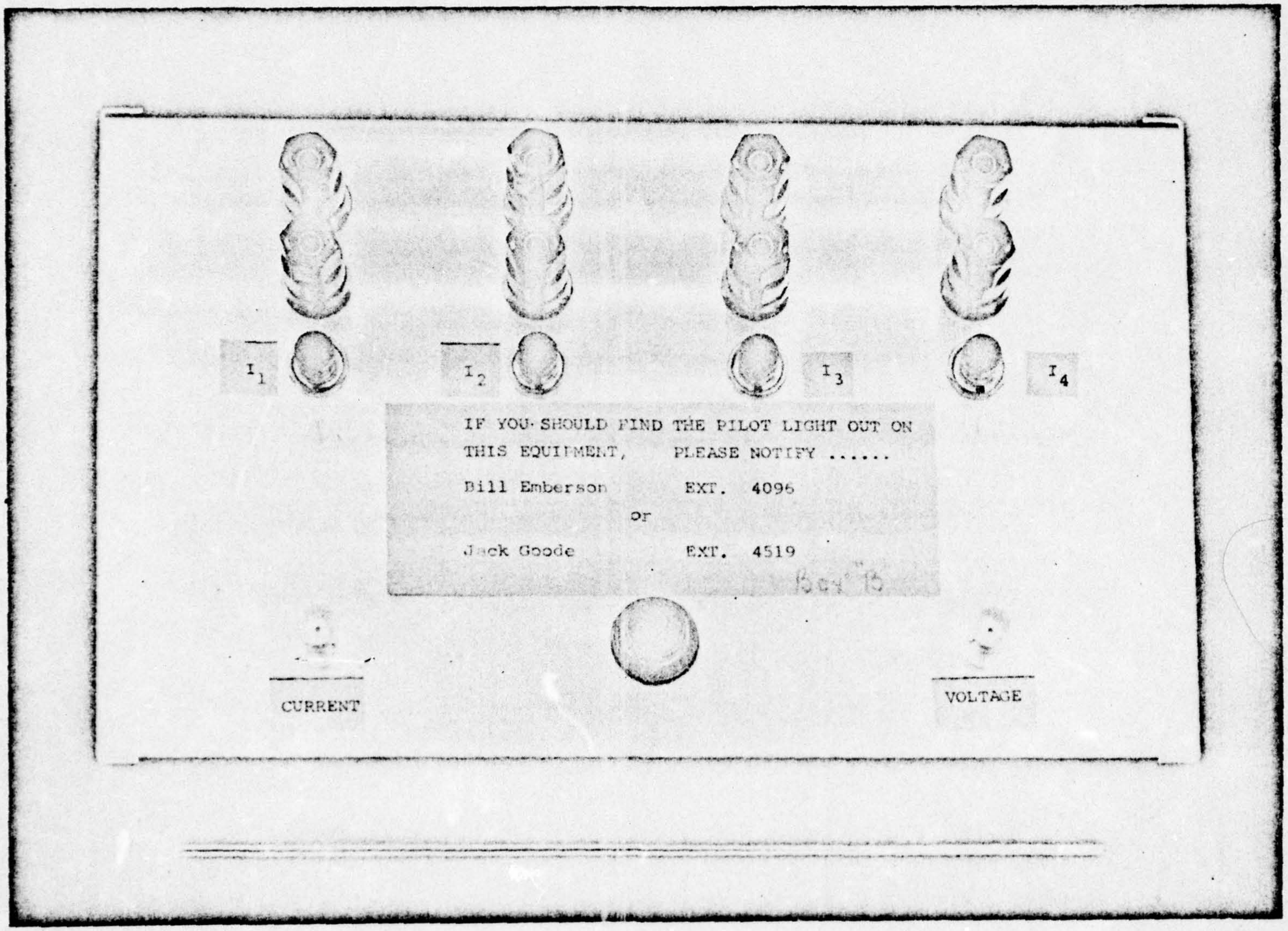

Figure A-2 Monitor Panel for E-field Simulator

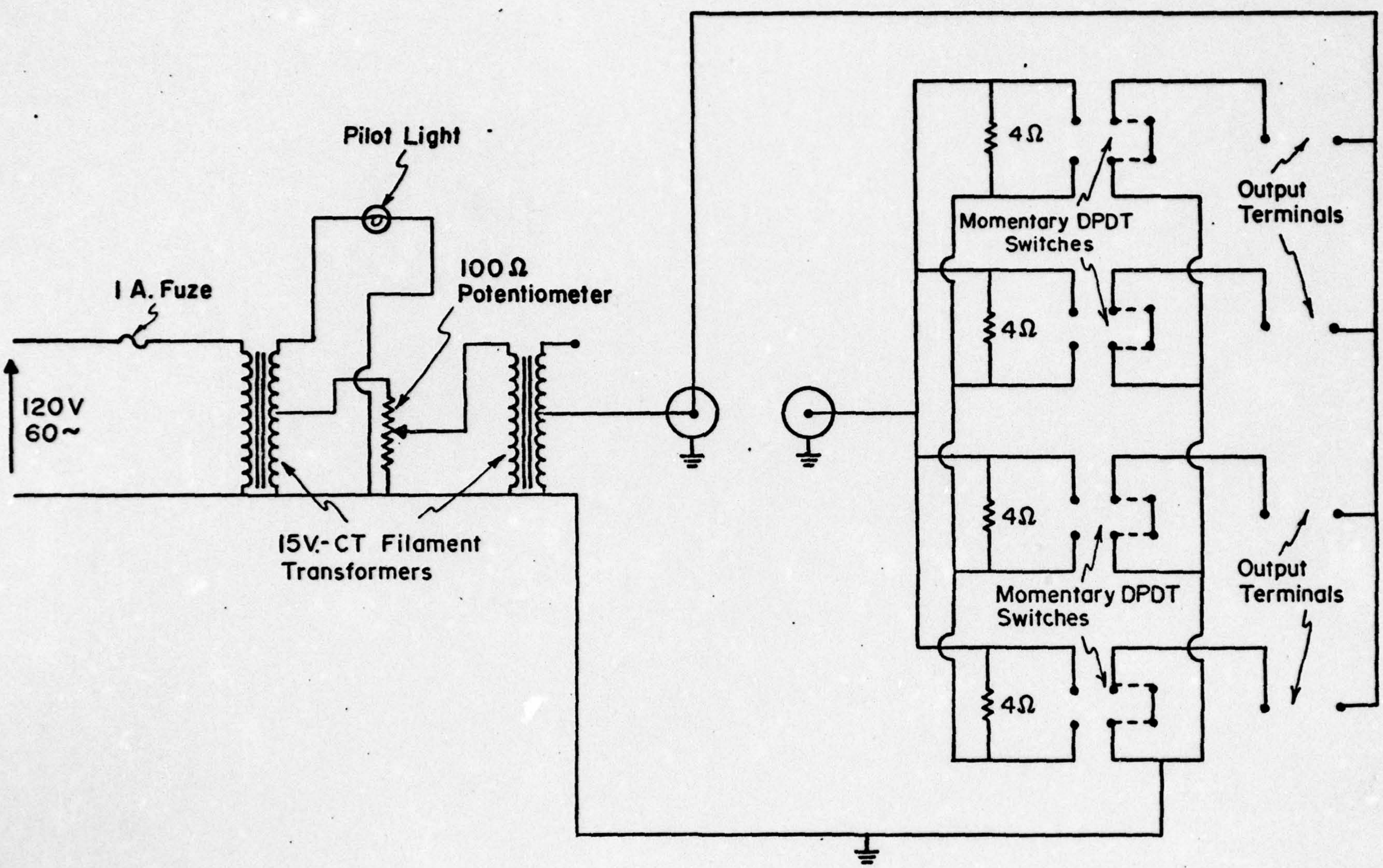

Fig. A-3 SCHEMATIC OF E-FIELD SOURCE

The other coaxial output and the momentary DPDT switches merely provide an easy method for measuring the current through each of the samples. When one of the momentary DPDT switches is pressed, a one-ohm resistor is inserted in series with the associated sample and the voltage drop across this one-ohm resistor is available at the coaxial output. Since the impedance of the soil samples is of the order of 150 ohms, it follows that the magnitude of the current through the sample and the voltage drop across the one-ohm resistor are essentially the same (i.e., 1 mV - 1 ma).

2.3 Preliminary Performance Tests

The output voltage of each of the sources was adjusted to 0.3 volt and the following preliminary performance tests were conducted for each source:

- Measure the output voltages while the load is varied from 30 to 2500 ohms.
- Measure the current through each of 4 load resistors (300 Ω).
- Measure the output voltage with 1 to 4 soil samples connected.
- Measure the current through each of 4 soil samples.

The results for each of the sources were essentially the same and were as follows:

- The output voltage remained at 0.3 volt as the load was varied from 30 to 2500 ohms.
- The measured current through each of the 300 ohm resistors was 1 ma (i.e., 1 mV at the coaxial output).
- The output voltage remained at 0.3 volt with either 1, 2, 3, or 4 soil samples connected.
- The current through each of the soil samples could be easily measured and ranged from 1.4 to 2.0 ma.

3. B-FIELD SIMULATOR

3.1 Introduction

One of the B-field simulators required for the laboratory studies of B-field effects on soil organisms is shown in the attached photographs

(Figures A-4, A-5). The following is a description of the B-field simulator design and the results of the preliminary performance tests.

3.2 B-Field Simulator Design

The basic design requirement of the B-field simulator for the Micro-eco experiment is that it must produce a uniform, 1 gauss 60 Hz magnetic field within the selected soil samples. The soil samples are one-foot cubes and eight of these samples must be subjected to a magnetic field. Because of the size of the soil samples and the lighting requirement, it was decided that the B-field simulator should be built in the form of coils. Further, it was decided that the field should not vary more than 10% within the test volume and each B-field simulator should be capable of holding four one-foot cube soil samples. In order to provide a simulator which would have a wide range of application, a 10 gauss capability was chosen as a design goal.

The first questions in the design are what type of coil configuration should be used and how large must the coils be to obtain the desired field uniformity within the required test volume. The obvious first guess is to use Helmholz coils with the spacing equal to the radius, since it can be shown that such a configuration provides an especially uniform field near the center. In order to determine how large the coils must be to obtain the desired uniformity within the required test volume, one must know how the field varies as you move away from the center. However, the expressions for determining the field at points other than along the axis are not readily available in literature. Therefore, the first step in the design was to derive the general expressions for the quasi-static magnetic field for a circular loop.

The magnetic vector potential for a circular loop of radius a is given by the following Equation A-1 for the cylindrical coordinate system shown in Figure A-6.

$$A_\phi = \frac{\mu_o I a}{\pi\sqrt{a^2 + z^2 + \rho^2 + 2a\rho}} \frac{(2-k^2)K(k)-2E(k)}{k^2} \qquad \text{(A-1)}$$

Figure A-4 Soil Samples in B-field Simulator

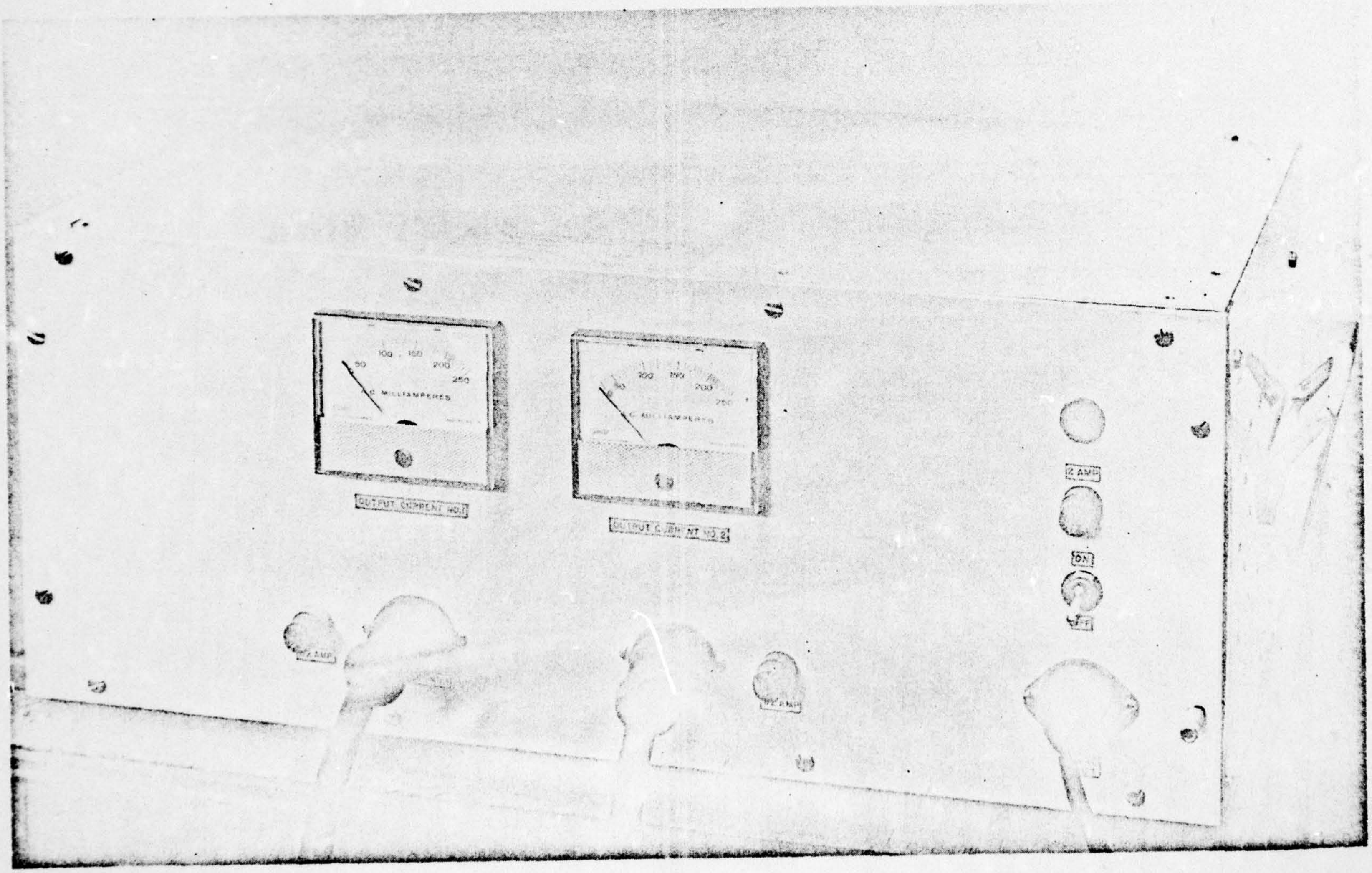

Figure A-5 Monitor Panel for B-field Simulator

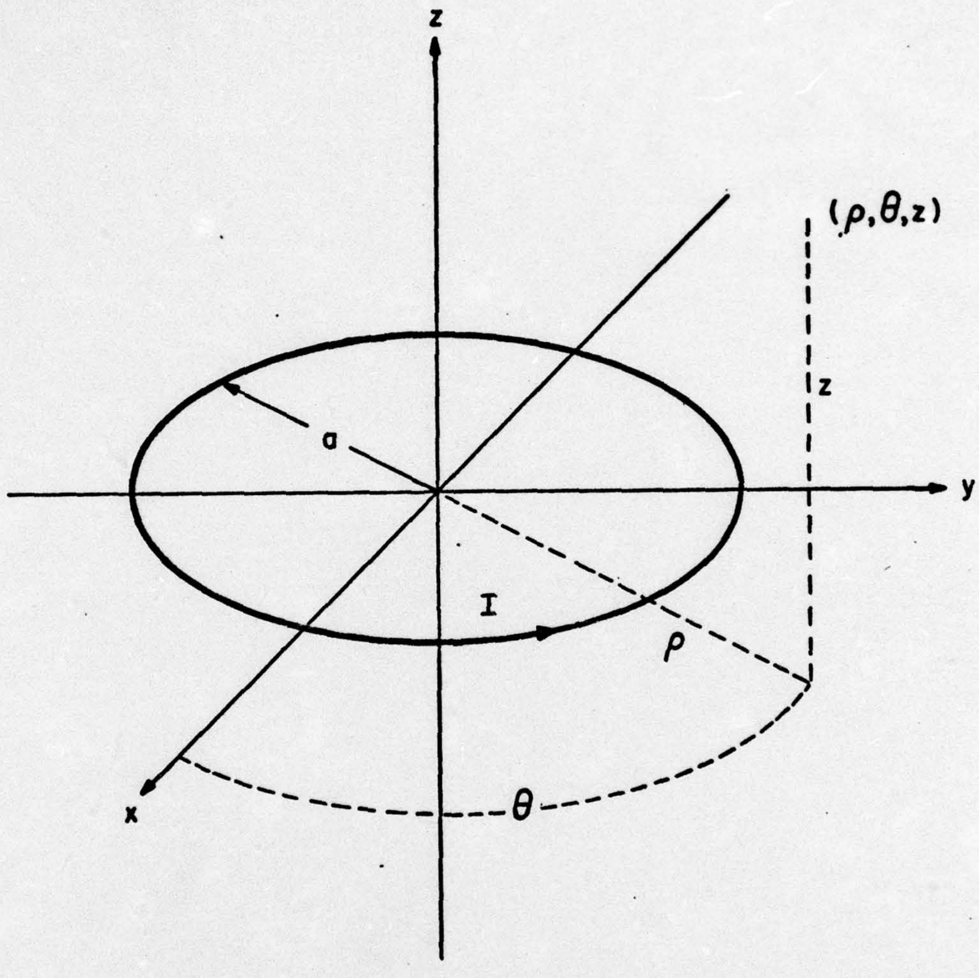

Fig. A-6 COORDINATE SYSTEM FOR LOOP ANALYSIS

where

$$k^2 = \frac{4a\rho}{a^2 + z^2 + \rho^2 + 2a\rho} \qquad \text{(A-2)}$$

K(k) = complete elliptic integral of the first kind

E(k) = complete elliptic integral of the second kind.

We know that the magnetic field is given by

$$\vec{B} = \nabla \times \vec{A} \qquad \text{(A-3)}$$

which in our case reduces to

$$\vec{B} = B_\rho \vec{I}_\rho + \vec{B}_z \vec{I}_z \qquad \text{(A-4)}$$

where

$$B_\rho = -\frac{\partial A\phi}{\partial \rho} \qquad \text{(A-5)}$$

and

$$B_z = \frac{1}{\rho} \frac{\partial(\rho A\phi)}{\partial \rho} \qquad \text{(A-6)}$$

Using Equations A-1, A-5 and A-6, it can be shown that

$$B_\rho = \left[\frac{\mu_o Ia}{\pi}\right] \left[\frac{m^3 z}{(1-k^2)}\right] \left[K(k) - (2-k^2)\, D(k)\right] \qquad \text{(A-7)}$$

and

$$B_z = \left[\frac{\mu_o I}{4\pi}\right] \left[\frac{m}{(1-k^2)}\right] \left[4a^2 m^2 E(k) + k^2(2-k^2)\, d(k) - k^2 K(k)\right] \qquad \text{(A-8)}$$

where

$$m = \frac{1}{\sqrt{a^2 + z^2 + \rho^2 + 2a\rho}} \qquad \text{(A-9)}$$

$$k = 2\sqrt{\frac{a\rho}{a^2 + z^2 + \rho^2 + 2a\rho}} \qquad \text{(A-10)}$$

K(k) = complete elliptic integral of the kind

$$= \frac{\pi}{2}\left\{1+\left(\frac{1}{2}\right)^2 k^2+\left(\frac{1\cdot 3}{2\cdot 4}\right)^2 k^4+\ldots\ldots+\left[\frac{(2n-1)!!}{2^n\cdot n!}\right]^2 k^{2n}+\ldots\ldots\right\} \quad \text{(A-11)}$$

E(k) = complete elliptic integral of the second kind

$$= \frac{\pi}{2}\left\{1-\frac{1}{2^2}k^2-\frac{1^2\cdot 3}{2^2\cdot 4^2}k^4\ \ldots\ldots-\left[\frac{(2n-1)!!}{2^n\cdot n!}\right]^2 \frac{k^{2n}}{(2n-1)}\ \ldots\ldots\right\} \quad \text{(A-12)}$$

$$D(k) = \frac{K(k)-E(k)}{k^2}$$

$$- \pi\left\{\frac{1}{1}\left(\frac{1}{2}\right)^2+\frac{2}{3}\left(\frac{1\cdot 3}{2\cdot 4}\right)^2 k^2+\ \ldots\ldots+\frac{n}{2n-1}\left[\frac{(2n-1)!!}{2^n\cdot n!}\right]^2 k^2(n-1)+\ \ldots\right\} \text{(A-13}$$

Equations A-7 through A-13 can be used to determine the quasi-static magnetic field due to a circular loop of radius a located as shown in Figure A-6. Further, by means of coordinate translation and superposition these euqations can be used to calculate the magnetic field at any point due to any number of coaxial loops. Therefore, these euqations were programmed and used to theoretically determine the field variation of various coil configurations.

Based on the theoretical analysis, it was determined that a 3-coil configuration would be better than a set of Helmholz coils with the spacing equal to the radius. Therefore, the B-field simulators were built using three coils as shown in the attached photograph. The couls have four-foot diameters and are spaced by one foot. The top and bottom coils have 236 turns of #14 wire; however, the center coil has only 118 turns of #14 wire. As predicted theoretically and confirmed experimentally, this configuration will produce the required one-gauss field when the current through each of the coils is 213 ma. Therefore, the three coils of each of the B-field simulators are driven in series using the source shown in the photograph. The source consists of an isolation transformer, two variacs and two 0-250 ma meters, so that the two simulators can be excited and monitored separately.

3.3 Preliminary Performance Tests

The first test performed was to adjust the current through each simulator to 213 ma and measure the magnetic field at the center. The measured magnetic field at the center of both simulators was 1.0 gauss as predicted.

The next test performed was to place four empty soil containers in each of the simulators and measure the field variation within the required test volume. The current through each simulator was adjusted so that the magnetic field at the center was 5.0 gauss (I - 1.06 amps) and the magnetic field was measured at 15 locations in each of the empty soil containers. The 15 locations measured were the top, center and bottom of the four corners and the center of the containers. As expected, the measured field ranged from 5.0 to 5.5 gauss for both of the simulators. Therefore, both of the B-field simulators satisfy the specified uniformity requirements (i.e., the field should not vary by more than 10 percent within the test volume)

The third test performed was to measure the magnetic field variation of one of the simulators for comparison with the theoretically predicted variation. The current through the simulator was adjusted so that the magnetic field at the center was 5.0 gauss (I - 1.06 amps) and the magnetic field was measured at the following locations (see Figure A-7 for the reference coordinate system):

- at two-inch intervals along the z-axis ($\rho = o$)
- at two-inch intervals along a radial in the plane of the center coil ($z = o$).

These experimental results were normalized to one gauss and are plotted in Figures A-8 and A-9 for comparison with the theoretically predicted fields. The theoretically predicted fields were calculated using the enclosed computer program, which is based on Equations A-7 through A-13. As shown in the figures, there is excellent agreement between the theoretical and experimental results.

Finally, temperature rise tests were performed on one of the 236-turn coils. Using a thermocouple attached to the bottom layer of wire, the coil temperature was measured as a function of time for various currents. The

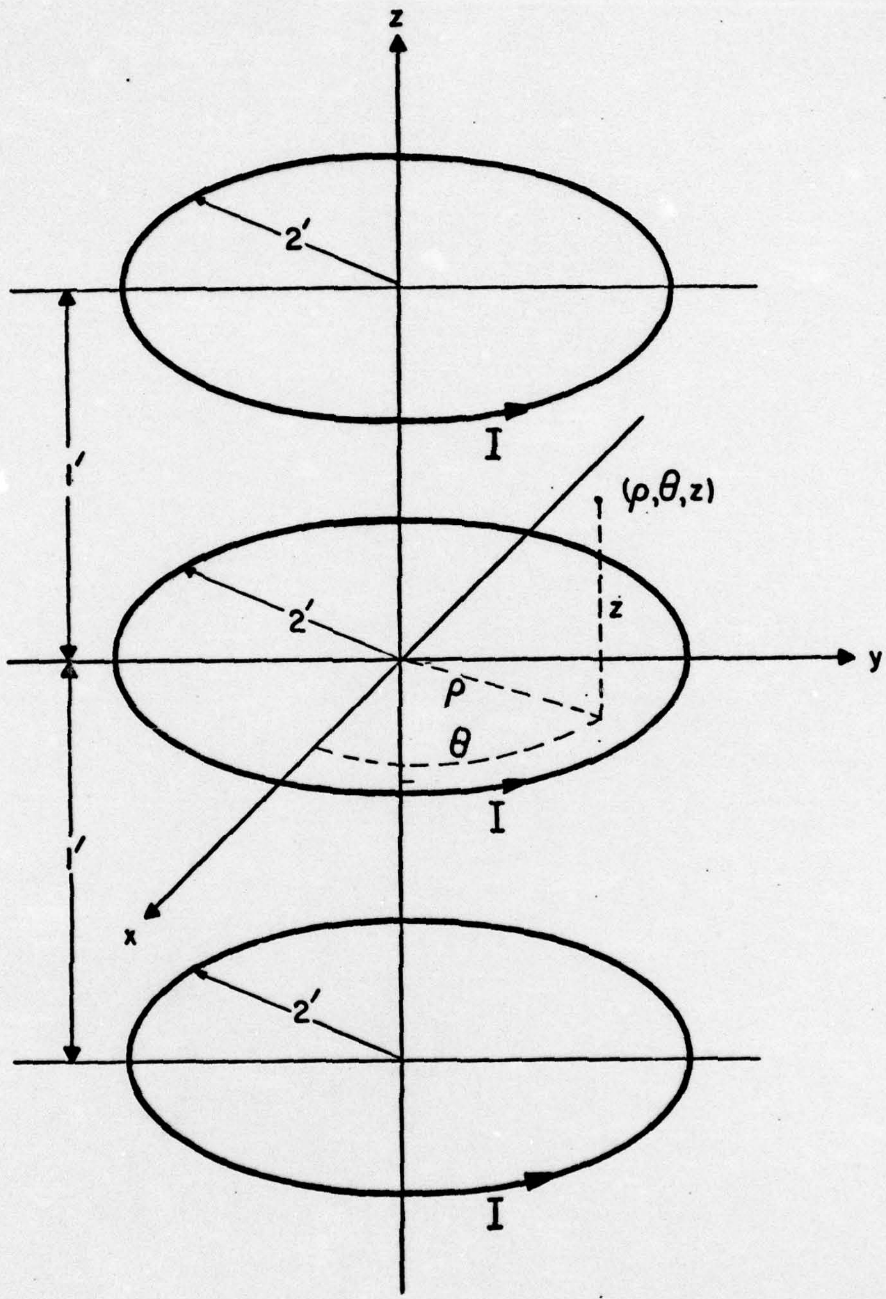

FIG. A-7 COORDINATE SYSTEM FOR 3-COIL CONFIGURATION

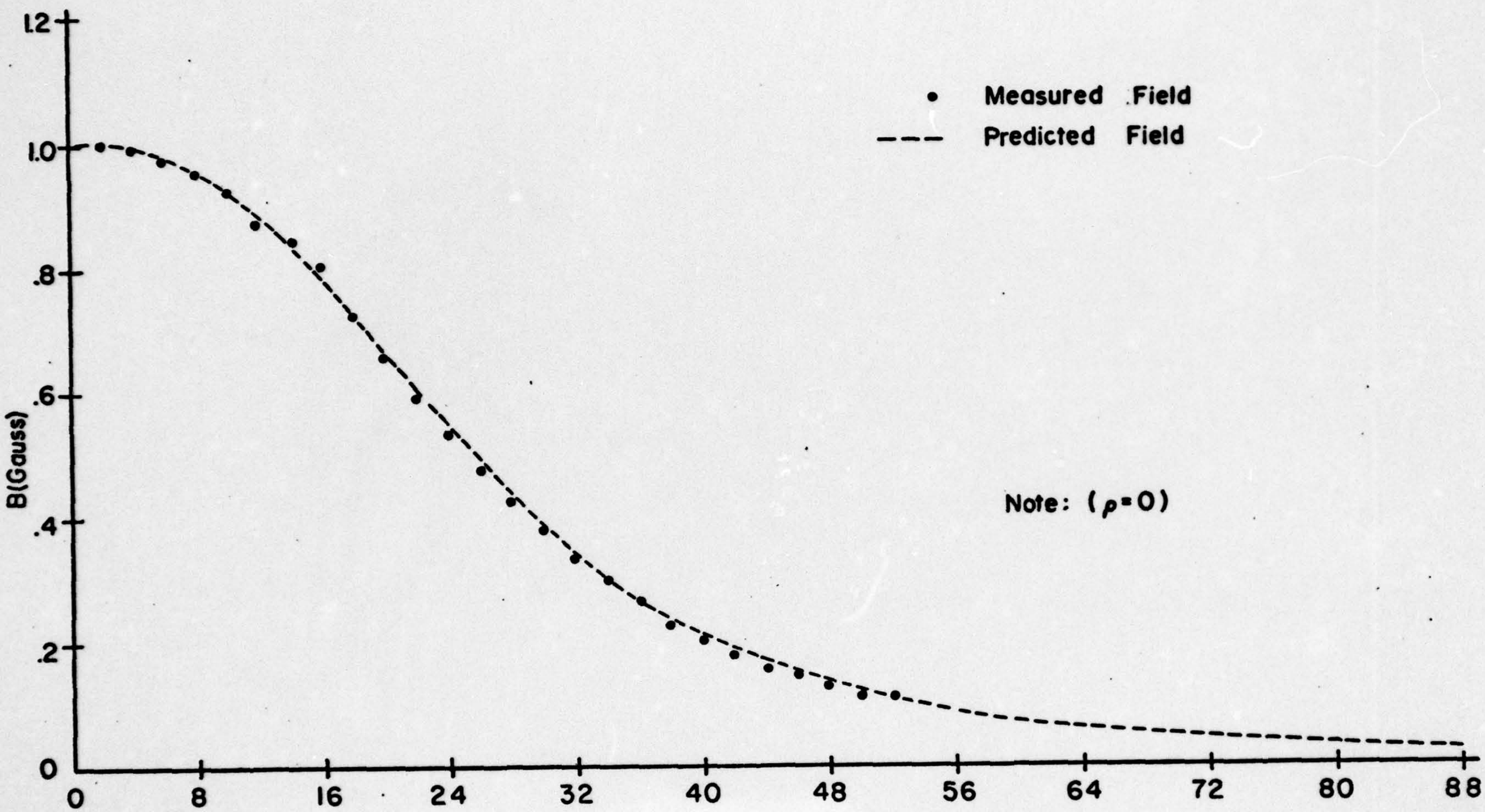

Fig. A-8 COMPARISON OF MEASURED AND PREDICTED MAGNETIC FIELD

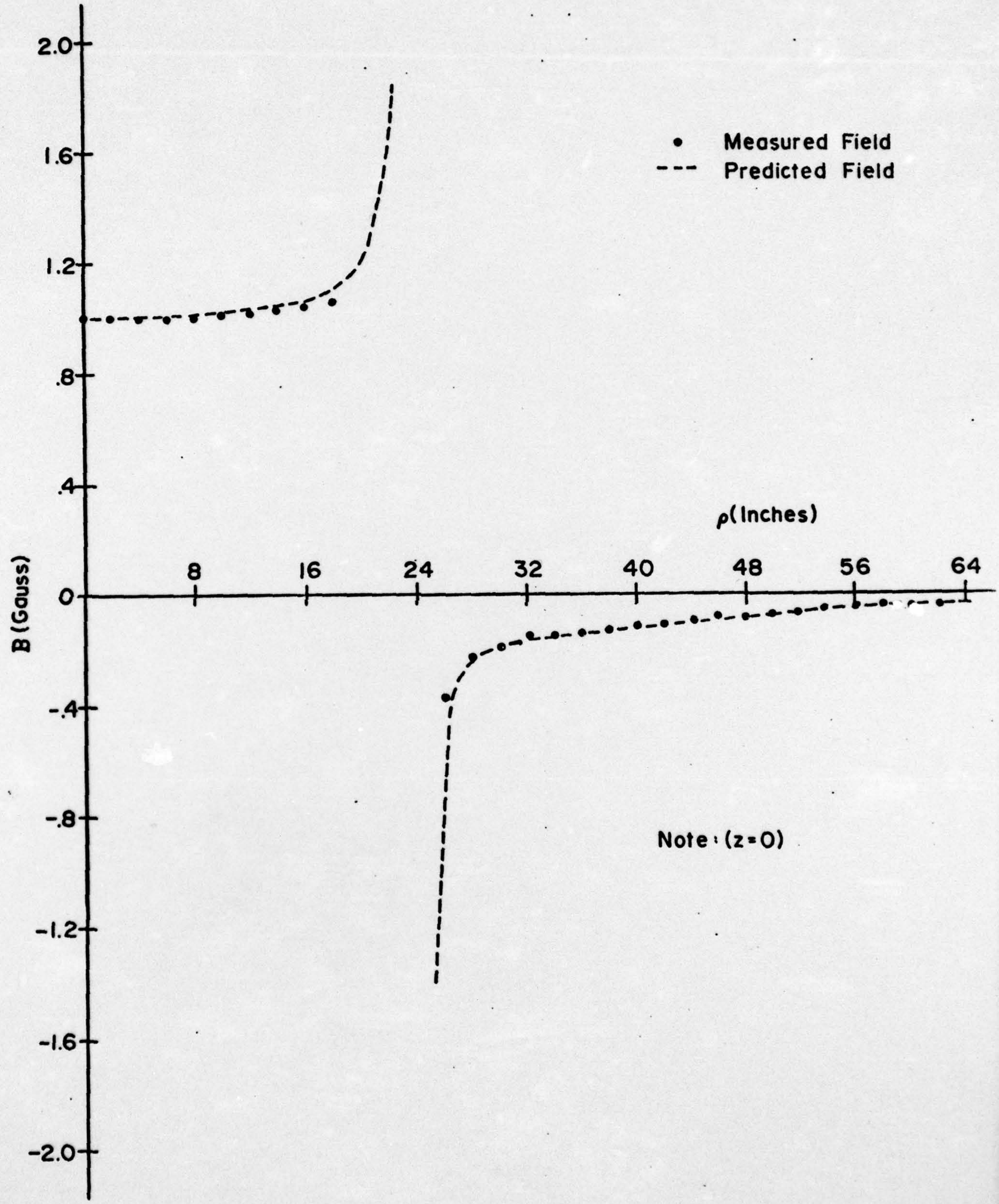

FIG. A-9 COMPARISON OF MEASURED AND PREDICTED MAGNETIC FIELD

experimental results are plotted in Figure A-10. As shown, the temperature rise for a current of 1.5 amperes is only approximately 2° centigrade. Therefore, the B-field simulators will remain essentially at room temperature when operated at the required one gauss (I = 213 ma). Further, it should be noted that the coil was operated for an hour at a current of 4.25 amperes and only attained a temperature of 47.5°C (127°F). Therefore, the present three-coil configuration is capable of producing a 20 gauss field for an extended period of time without overheating.

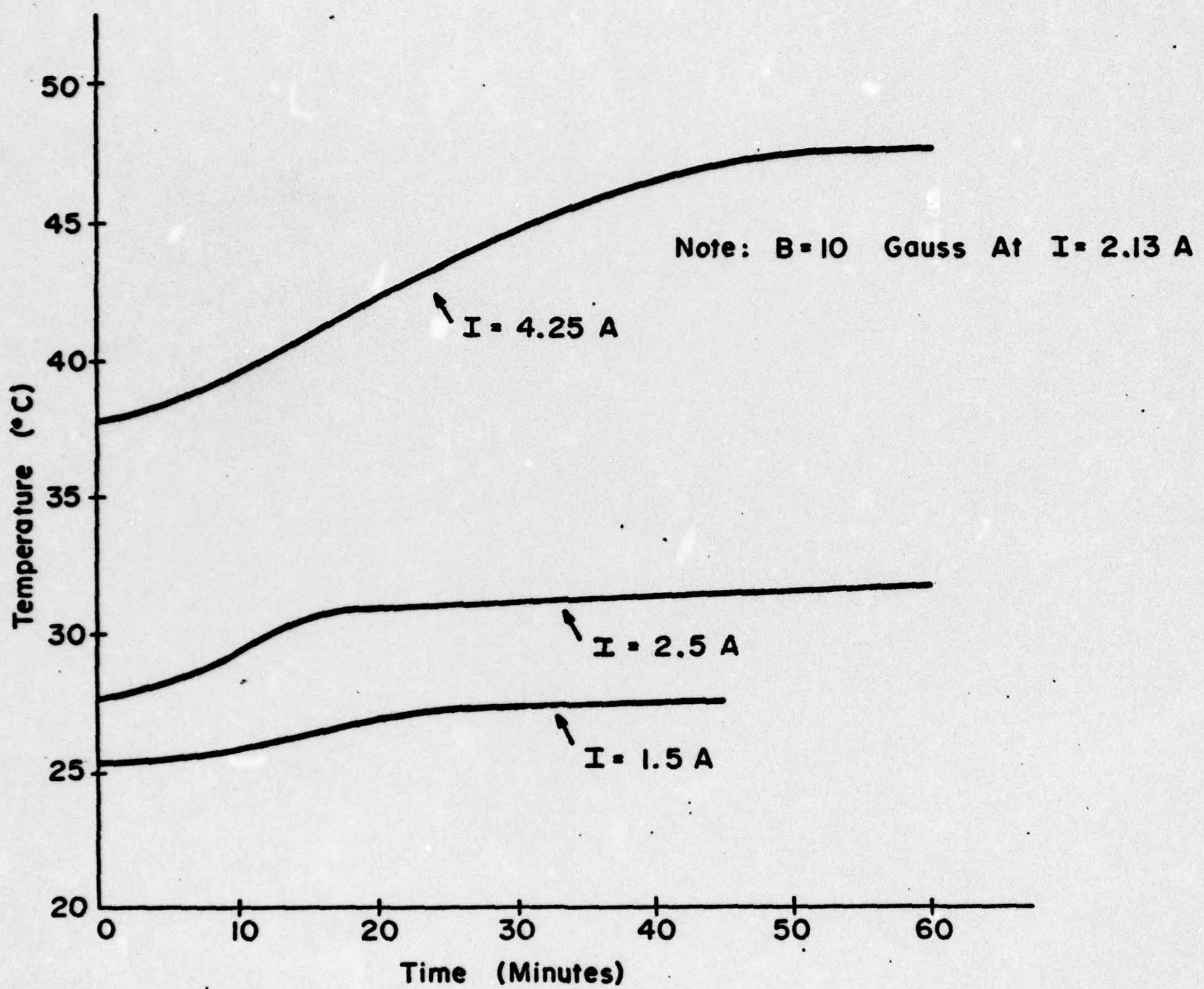

Fig. A-10 TEMPERATURE RISE VERSUS TIME FOR VARIOUS CURRENTS

REFERENCES

A-1. J. D. Jackson, Classical Electrodynamics, John Wiley & Sons, Inc., New York (1962, Chapter 5, pp 141-142.